Accelerated Testing Methodology Developed for Determining the Slow Crack Growth of Advanced Ceramics

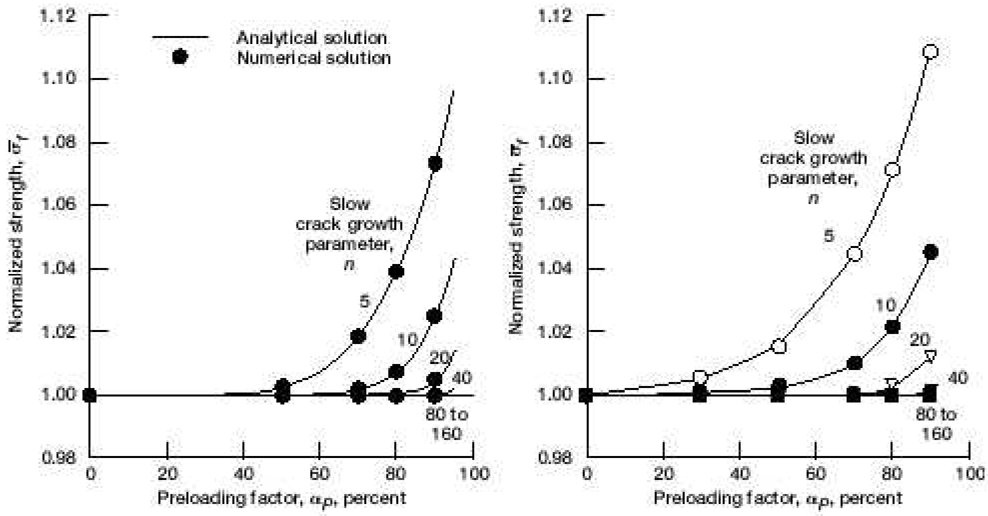
Constant stress-rate ("dynamic fatigue") testing has been used for several decades to characterize the slow crack growth behavior of glass and structural ceramics at both ambient and elevated temperatures. The advantage of such testing over other methods lies in its simplicity: strengths are measured in a routine manner at four or more stress rates by applying a constant displacement or loading rate. The slow crack growth parameters required for component design can be estimated from a relationship between strength and stress rate.

With the proper use of preloading in constant stress-rate testing, test time can be reduced appreciably. If a preload corresponding to 50 percent of the strength is applied to the specimen prior to testing, 50 percent of the test time can be saved as long as the applied preload does not change the strength. In fact, it has been a common, empirical practice in the strength testing of ceramics or optical fibers to apply some preloading (<40 percent). The purpose of this work at the NASA Lewis Research Center is to study the effect of preloading on measured strength in order to add a theoretical foundation to the empirical practice.

An analytical and numerical solution of strength as a function of preloading has been developed, as shown in the graph. In this solution, $\bar{\sigma}_f$ is the normalized strength, in which the strength with preloading is normalized with respect to the strength with zero preloading; and α_p is the preloading fraction

$$(1 \leq \alpha_p < 1)$$

where the preloading stress is normalized with respect to the strength with zero preloading. Finally, n is the slow crack growth parameter used in the expression of slow crack growth rate, $v = da/dt = A(K_I/K_{IC})^n$, where v, a, t, A, K_I, and K_{IC} are the crack velocity, crack size, time, slow crack growth parameter, stress intensity factor, and fracture toughness, respectively. The solution has been verified with experimental results obtained from constant stress-rate testing of glass and alumina at room temperature and of alumina, silicon nitride, and silicon carbide at elevated temperatures.



Normalized strength, $(1 \le \alpha_p < 1)$*, as a function of preloading factor,* a_p*. Left: Natural flaw system. Right: Indentation-induced flaw system with residual stress field.*

The most direct and powerful effect of preloading is the reduction of test time, which greatly affects test efficiency. For example, if it takes about 9 hr to perform constant stress-rate testing on one ceramic specimen and if a minimum of 20 specimens are required to obtain reliable statistical data, the total testing time at that stress-rate would be 180 hr. However, if a preloading of 80 percent was applied, the total testing time would be reduced to 36 hr, saving 80 percent of the total test time. For a preload of 70 percent, 70 percent of the time would be saved, and so on. The use of preloading has been adopted in a recently established American Society for Testing and Materials standard (C1368) on slow crack growth testing of advanced ceramics.

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